

Excess Body Fat Lessens the Metabolic Response to Cold Exposure

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Abstract

Extensive research has been conducted to study the effects of body fat on physiological responses under various environmental conditions. Experiments involving extreme situations, such as cold water immersion and cold air exposure wearing minimal clothing, are in greater abundance than those replicating more common human cold interactions. The purpose of this study was to measure the influence of percent body fat (%BF) on oxygen consumption [VO_2 ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)] and mean blood pressure [MAP (mmHg)] at rest and during exercise in an environment simulating cold winter conditions. Subjects included 30 healthy, male volunteers, age 19-42 years who were not regularly active prior to the experiment. Testing was completed in an environmental chamber set to a temperature of 5°C with 30%-50% humidity. Subjects were asked to wear a t-shirt, winter coat, winter gloves, and exercise pants. Oxygen consumption and blood pressure were measured inside the environmental chamber while subjects were seated quietly for five minutes and during a 5-minute, low-intensity exercise period.

Results showed %BF was negatively correlated with VO_2 at rest ($r = -.552$, $p < 0.01$) and during exercise ($r = -.503$, $p < 0.01$) and positively correlated with MAP ($r = .402$, $p < 0.05$) in the cold. This supports the notion that body fat attenuates the muscle activation caused by shivering, which is responsible for increased oxygen consumption. It also provides evidence for blood pressure elevations associated with excess body fat. The findings suggest that during typical outdoor winter exposure, those with higher %BF are less likely to exhibit the shivering response at a level of those with lower %BF.

Background

This study stems from a dissertation research project conducted by Dennis Kerrigan, Ph.D. The project, entitled “The Effect of a Resistance Training Program on Various Cardiovascular Indices during Acute Cold Exposure”, was a longitudinal study to assess changes in cardiovascular responses to cold exposure following an 8-week resistance training regimen. Variables of interest included QTc interval, arterial stiffness, rate pressure product (RPP), cardiac output, stroke volume, and total peripheral resistance.

The present experiment was conducted as part of Kerrigan’s project. However, this was treated as a cross-sectional study in which only baseline data was analyzed. The main variables of interest were body fat percentage, VO_2 at rest and during exercise in the cold, and MAP in the cold. Correlations were run between these variables in hopes that significant associations would be found. The same subjects, methods, and data were used in both studies.

Introduction

Cold exposure stresses the human body by making it more difficult to maintain core temperature. The physiologic stress endured during cold exposure is evident when measuring changes in heart rate, blood pressure, and oxygen consumption. As the body loses heat to the environment primarily through convection and radiation, a shivering response is initiated. Under such conditions, the innate mechanism of muscle shivering is triggered to produce heat which is marked by an increase in oxygen consumption, or VO_2 . Simultaneously, peripheral vasoconstriction occurs to decrease the amount of blood (and heat) reaching the skin’s surface in an effort to preserve the core temperature. A natural consequence of this shunting is an increase in blood pressure.

The central factors affecting the degree of one's physiologic responses to cold exposure in this experiment include the severity and medium of cold stress, clothing, physical activity, and body fat. A recognized function of body fat is its ability to insulate the body in cold conditions. Fat, particularly that distributed subcutaneously, resists the flow of heat from the periphery to the atmosphere.¹ With less heat loss, people with more body fat should require less heat production than their lean counterparts under similar conditions. Many studies have reported positive findings in investigating the relationship between body fat and thermoregulatory response to support this claim.^{3,4,5} Although it might be considered advantageous to have excess body fat in a cold environment, the effects of adiposity in general, and on blood pressure specifically, may be deleterious. Individuals with higher body fat content tend to have higher blood pressures according to epidemiological surveys³, so the additional cold-induced increase in blood pressure would cause greater cardiovascular stress.

Cold water exposure typically elicits a stronger response than cold air because at equal temperatures, water conducts heat approximately 25 times faster than air.¹ For this reason, extensive cold stress research has been conducted using cold water as a medium. Tikuisis et al. reported that body fat had been shown to lessen the metabolic and shivering responses in cold water immersion in previous studies, but the mechanism had not been investigated in cold air.⁵ Furthermore, many experiments use extreme cold conditions to generate stronger reactions. Studies of cold air exposure commonly experienced by the general population are more limited, thus that was the environment simulated in the present experiment.

Clothing provides insulation, acting as a barrier between the cold and the surface of the skin. Multiple layers of clothing provide the best insulation, since the fabric traps and warms air before it reaches the body. However, when exercising in a cold environment, clothing can be an

added stress if it hinders evaporation of sweat or heat loss associated with exercise cooling.¹ The need for insulation decreases during exercise as heat production increases, but exercise does not always produce an adequate amount of heat to maintain core temperature.^{1,2} It also leads to an additional increase in VO_2 above that associated with the shivering response. Many cold experiments allow only minimal clothing to eliminate its influence on thermoregulation. However, Weller et al. reported significant changes in VO_2 from exercise in a thermoneutral environment to exercise in 5°C while subjects wore combat uniforms.⁶ Clothing may be acceptable provided the cold stress is sufficient to cause a shivering response.

At rest in a thermoneutral environment, the average VO_2 is $3.5 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$.⁷ This value is higher at rest during cold exposure due to the shivering response. Exercise in a cold environment would elevate one's VO_2 above that attained as a result of shivering. During submaximal exercise, more fit individuals generally have lower VO_2 values than sedentary individuals at the same intensity. For people of equal fitness levels, those with lower body fat would likely have lower VO_2 values at equal exercise intensity because lean tissue extracts oxygen more efficiently than fat. However, these patterns could be altered in a cold environment, as those with greater body fat percentages would typically exhibit lower VO_2 values at rest in the cold.¹ To determine the optimal intensity to study physiologic responses to exercise in the cold, Weller et al. compared two protocols of low- and high-intensities. They found that subjects experienced more significant physiologic changes during low-intensity walking ($\sim 30\% \text{VO}_{2\text{max}}$) than high-intensity walking ($\sim 60\% \text{VO}_{2\text{max}}$).⁶

The purpose of this study was to investigate the effect of body fat on VO_2 during typical exposure and activity in a simulated winter weather environment. To imitate common cold-weather activity, subjects wore winter coats and exercise pants and engaged in low-intensity

walking while holding a weight. This could be comparable to walking to class or work during the winter while carrying a bag or suitcase. It was hypothesized that during cold exposure under equivalent conditions, men with greater body fat percentages would have lower VO_2 measurements at rest than those with less body fat. During low-intensity exercise in the cold subjects with lower %BF would still have higher VO_2 values, since the exercise-induced heat production would not be sufficient for maintenance of core temperature. Lastly, subjects with higher %BF would have higher blood pressures than their lean counterparts at rest and during exercise in the cold environment.

Methods

Subjects included 30 healthy, male volunteers, age 19-42 years old (26.9 ± 6.1). They were recruited on and around the Ohio State University main campus in Columbus, Ohio by word of mouth and through the faculty fitness program. An exclusion criterion included present participation in regular activity prior to the experiment. This meant that qualified subjects were not meeting the ACSM guidelines for aerobic exercise and were not engaging in any more than 1 day of structured resistance training per week in the month prior to testing.⁸ Subjects were asked to complete a Godin Leisure-Time Physical Activity Questionnaire to further assess activity levels.⁹ All participants provided informed consent and the experiment was approved by the Institutional Review Board.

Standard anthropomorphic measurements were taken on the first day of testing. Subjects' heights were measured without shoes using a stadiometer. Bodyweight was measured using an electronic scale calibrated with a 20kg weight. A tape measure was used to determine waist circumference at the narrowest portion of the abdomen. Skinfold thickness was measured using

Lange calipers at the chest, abdomen, and thigh, which are the male-appropriate sites designated by Jackson and Pollock.¹⁰ The method used to estimate body fat percentage was air displacement plethysmography (Bod Pod, Concord, CA) and the Siri equation. During Bod Pod measurements all subjects wore the suggested compression shorts and swim cap.¹¹ Blood pressure was measured with a mercury-sphygmomanometer. Mean Arterial Pressure (MAP) could then be calculated using the equation $((\text{SBP}-\text{DBP})/3) + \text{DBP}$ where SBP is systolic blood pressure and DBP is diastolic blood pressure.

Aerobic and resistance testing was also completed on participants' first day. A Bruce Protocol treadmill test was used to assess maximal aerobic capacity. This protocol measured VO_2 via indirect calorimetry (Parvo Medics True One Metabolic System package, OUSW Version 3.5, 2003) while subjects exercised in stages of gradually increasing speed and incline. Heart rate was monitored via a 12-lead ECG and Polar heart rate monitor. The test was ended when the subjects determined they could no longer proceed. $\text{VO}_{2\text{max}}$ was estimated by eliminating the highest and lowest VO_2 values measured during the last minute of testing and averaging the remaining two values.

A 1-RM arm curl was conducted to decide what weight would be appropriate for each individual to hold during the exercise portion of the cold-exposure experiment. Subjects first warmed up by completing 8-12 repetitions at 40% of their estimated 1-RMs. Next, they stood with their backs against a wall, knees slightly bent, and feet shoulder-width apart for proper support. The weight chosen by each subject for his first 1-RM attempt was then handed to him in his outstretched arm and he was asked to complete an arm curl through one full range of motion (ROM). Subjects were given 3-5 trials to reach a maximum resistance, with 3 minutes rest between trials. If a subject did not complete a full ROM, they were given a 5 minute resting period

after which they could try again. The highest weight achieved with successful technique was considered the 1-RM. The weight held during the exercise phase of cold exposure was determined by calculating 50% of the 1-RM.

The cold-exposure experiment was conducted on participants' second day of testing. An environmental chamber (Tuscor Inc., Warminster, PA) was used to create winter weather conditions. It was set at 5°C with 30-50% humidity. Subjects were asked to wear a t-shirt, winter coat, winter gloves, and exercise pants. Before entering the chamber, heart rate was monitored at rest via a 12-lead ECG in a 21°C room for 5 minutes followed by blood pressure measurement. Once in the chamber, subjects were fitted with the necessary headgear, mouthpiece, and nose clip for VO₂ measurement (Parvo Medics True One Metabolic System package, OUSW Version 3.5, 2003). The rest period was 5 minutes long. During this time heart rate and blood pressure were measured. Following the resting period subjects began walking on the treadmill at 3.0 mph, which they were allowed to adjust to a comfortable pace. A dumbbell equal to 50% of the weight achieved during 1-RM arm curl testing was then handed to the subject for him to carry with his arm straight. VO₂ and heart rate were monitored continuously during rest and exercise, and blood pressure measurements were again taken during the exercise period.

Statistical Analysis

A priori alpha level was set at $p \leq 0.05$. Pearson correlations were used to investigate relationships between the designated variables: body fat percentage, VO₂, and MAP. Statistical analysis was completed using SPSS software version 15.0 (SPSS, Chicago, IL, USA) and Microsoft Office Excel 2007. Data is displayed as means \pm standard deviations.

Results

Significant negative correlations were found between %BF and resting VO_2 ($r = -0.552$, $p < 0.01$, see figure 1) and %BF and exercise VO_2 ($r = -0.503$, $p < 0.01$, see figure 2). As displayed in figure 3, a significant positive correlation ($r = 0.402$, $p < 0.05$) was found between %BF and MAP in the cold. Table 1 provides means with standard deviations of selected demographic and physiological variables.

Table 1

Variable	Baseline
Age (years)	26.9 ± 6.1
Body fat (%)	23.4 ± 8.4
VO_2max ($\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	40.0 ± 6.4
Cold Resting VO_2 ($\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	4.2 ± 1.3
Cold Exercise VO_2 ($\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	16.2 ± 2.8
Euthermic MAP (mm Hg)	82.7 ± 9.1
Cold MAP (mm Hg)	90.2 ± 9.9

Data expressed as mean \pm SD

Figure 1

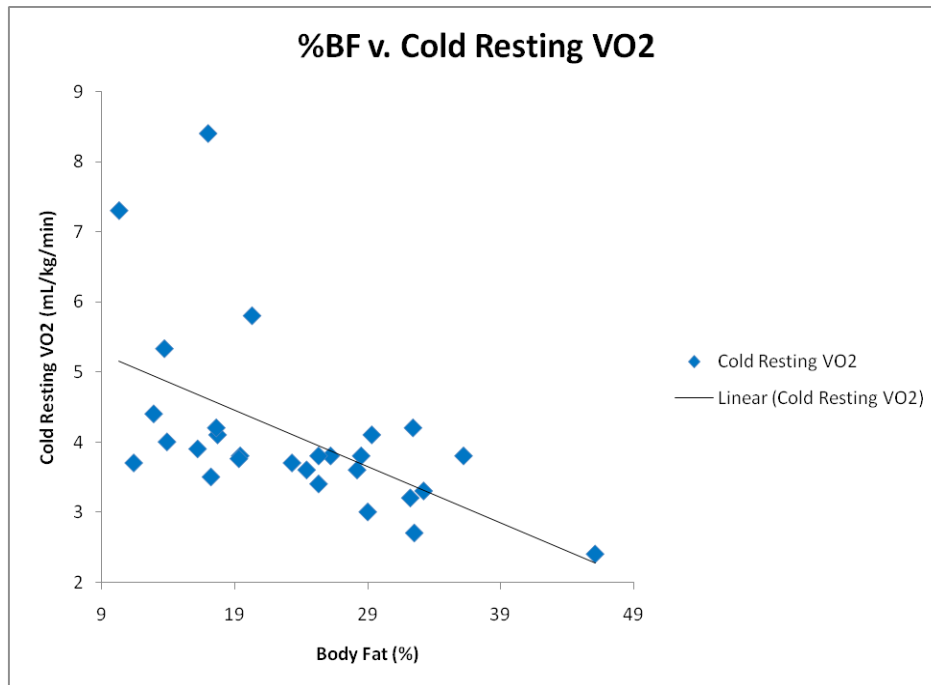


Figure 1. Graph of body fat percentages and VO₂ values at rest during cold exposure for individual subjects. A trendline shows the negative correlation between variables.

Figure 2

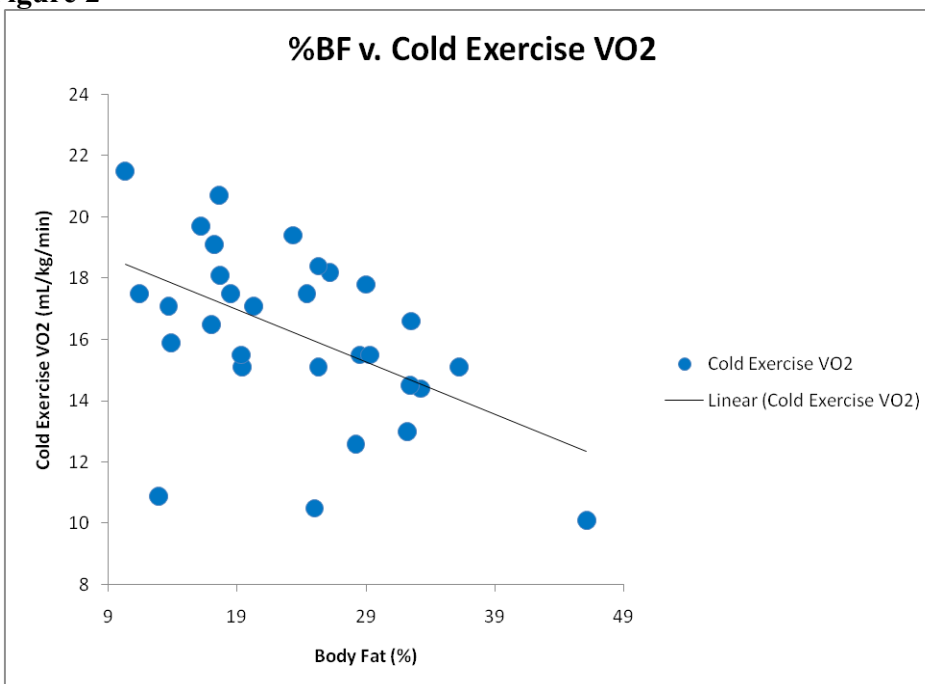


Figure 2. Graph of body fat percentages and VO₂ values during low-intensity exercise in the cold for individual subjects. A trendline shows the negative correlation between variables.

Figure 3

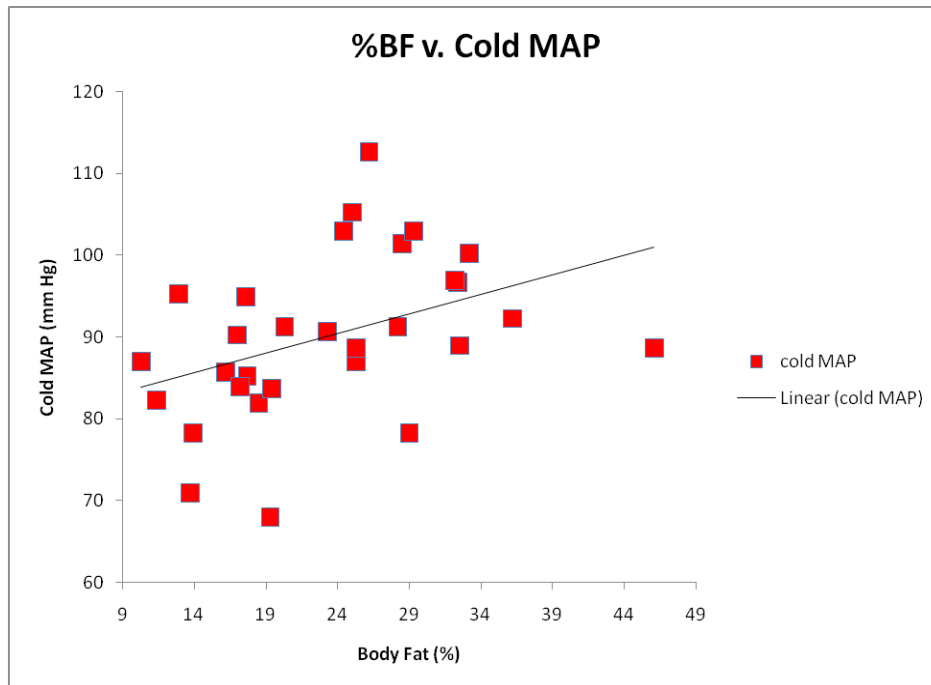


Figure 3. Graph of body fat percentages and MAP measurements during cold exposure for individual subjects. A trendline shows the positive correlation between variables.

Discussion

As hypothesized, Figure 1 shows that individuals with lower body fat percentages tended to have higher VO_2 values at rest during cold air exposure. This is likely due to a more intense shivering response in an effort to maintain core temperature. Onset of shivering occurs when afferent cold receptors of the internal organs, skin, and spinal cord relay the sensory information to the hypothalamus during cold exposure.¹² The hypothalamus then activates skeletal muscles (i.e. shivering) via motor nerves in the efferent pathway, resulting in heat production and increased VO_2 . Vasoconstriction occurs when skin blood vessels receive the message from the hypothalamus via sympathetic nerves in the efferent pathway.¹² Those with higher body fat percentages benefit from the insulation provided by the adipose tissue by requiring less heat

production. However, because those with more body fat tend to have higher blood pressure under normal conditions, the vasoconstriction experienced during cold exposure is detrimental.

Those with higher body fat percentages also tended to have lower VO_2 values during the low-intensity exercise phase of cold exposure, as shown in figure 2. The correlation for cold exercise VO_2 was slightly weaker than that seen between cold resting VO_2 and %BF. It is possible that subjects with higher %BF had more significant increases in VO_2 from rest to exercise, since they tend to have greater VO_2 values than their lean counterparts during submaximal exercise under normal conditions. Ultimately, those with lower body fat seemed to experience greater stress than those with higher body fat during the exercise phase of the study, contrary to what would be expected in a thermoneutral environment.

Figure 3 supports the hypothesis that those with greater body fat percentages tend to have higher mean blood pressures during cold exposure. As explained previously, this is due to the propensity for overweight and obese individuals to have higher blood pressures than their lean counterparts under similar conditions. The additional stress placed on blood vessels during cold exposure as a consequence of vasoconstriction-induced increases¹² is of more concern for those with higher body fat percentages.

Limitations

Some confounding variables were encountered in the experiment that could have affected the outcome. One such variable would be the clothing worn by subjects in the cold chamber. Most subjects supplied their own winter coats, winter gloves, exercise pants, and t-shirts which created variation between subjects. Although guidelines were provided to help regulate what type of clothing was worn, the fact that the same clothing was not used in each experiment could have

created differences in the responses of each individual to the cold stress. Furthermore, having the subjects wear standard winter clothing makes it difficult to isolate the influence of body fat, since clothing provides an extra layer of insulation. It also decreases radiative and convective heat loss, which accounts for 70% of heat loss in a cool, dry environment, by acting as a barrier between the cold air and skin surface.¹² Another variation to consider would be age, as subjects ranged from 19-42 years old. Research suggests that as people age their thermoregulatory response weakens. It is unclear, however, whether this is due to chronological age or differences in body composition commonly associated with aging.^{3,4} If age is the main factor, it could be considered a confounding variable. However, if changes in body composition are the reason, it was accounted for in body fat measurements.

Conclusion

The major findings of this study were that body fat percentage is negatively correlated with VO_2 at rest and during exercise in a cold environment and positively correlated with mean blood pressure in a cold environment. Although causation cannot be implied from these findings, it can be said that associations between variables exist. Excess body fat appears to be advantageous under typical winter conditions, however it does seem to increase mean blood pressure. When preparing for cold air exposure, multiple layers are best to maintain body temperature when thermogenesis is insufficient. Evidently wearing a t-shirt, winter coat, exercise pants, and winter gloves does not provide enough insulation to avoid the shivering response and subsequent rise in VO_2 above the normal resting value of $3.5 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ in euthermic conditions. Those with low body fat percentages may require more layers than those with high body fat percentages to maintain core temperature under similar cold conditions.

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